NASA Research Grant Progress Report

For the Period: 4/1/92-1/8/93

Dynamics of the Solid Earth (DOSE) Program

Kinematics of the New Zealand Plate Boundary: Relative Motion by GPS Across Networks of 1000 km and 50 km Spacing

NASA Grant N. NAG 5-1957

University Navstar Consortium (UNAVCO)/ University Corporation for Atmospheric Research (UCAR)

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Overall Project Principal Investigator: Prof. Richard Walcott, Victoria University, Wellington, New Zealand

Project Overview

The NASA/DOSE "Kinematics of the New Zealand Plate Boundary" experiment is a four-year cooperative Global Positioning System (GPS) experiment involving 6 universities and institutions in New Zealand and the United States. The Principle Investigator of the experiment is Professor Richard Walcott at Victoria University of Wellington. The direct NASA/DOSE contributions to the experiment were split between the University Navstar Consortium [UNAVCO], Meertens, Rocken and Perin CO-Is, and Lamont-Doherty Geological Observatory [LDGO], Scholz and Beavan CO-Is. New Zealand Co-Is include Des Darby (Institute of Geological and Nuclear Sciences [IGNS], Peter Koons (Otago University), and John Hannah (Dept. of Survey and Land Information [DOSLI]). The Jet Propulsion Laboratory [JPL] and UNAVCO provided experiment preparation and field support. The remainder of the funding was contributed by the New Zealand groups. We estimate their contribution to be approximately 2 to 3 times the U.S. amount.

The investigation covers two scales, the first on the scale of plates (~1000 km) and the second is on the scale of the plate boundary zone (~50 km). In the first portion of the experiment, which we call Phase A, the objective is to make direct measurements of tectonic plate motion between the Australian and Pacific plates using GPS in order to determine the Euler vector of this plate pair. The Phase A portion of this experiment was initiated in December 1992 with the first-epoch baseline measurements on the large scale network. This network will be resurveyed two years later to obtain velocities. The stations which were observed for Phase A are shown in Figure 1 and are listed in Table 1. Additional regional stations which will be used for this study are listed in Table 2 and are part of either CIGNET or other global tracking networks. The Phase A portion of the experiment is primarily the responsibility of the UNAVCO investigators. This report therefore concentrates on Phase A. The Year 1 NASA funding for Phase A included only support for the field work. Processing and analysis will take place with Year 2 support.

The second part of the experiment measured relative motion between the Australian and Pacific plates across the plate boundary zone between Hokitika and Christchurch on the South Island of New Zealand. The extent and rate of deformation will be determined by comparisons with historical, conventional surveys and by repeated GPS measurements to be made in two years. This activity was the emphasis of the LDGO portion of the study. An ancillary experiment, Phase C, concentrated on plate boundary deformation in the vicinity of Wellington and was done as part of training during the early portion of the field campaign.

Details of the objectives of the field investigations are given in Appendix I. An overview of the 1992 GPS field program is given in Appendix II which is a copy of the Project Plan, put together by VUW and IGNS.

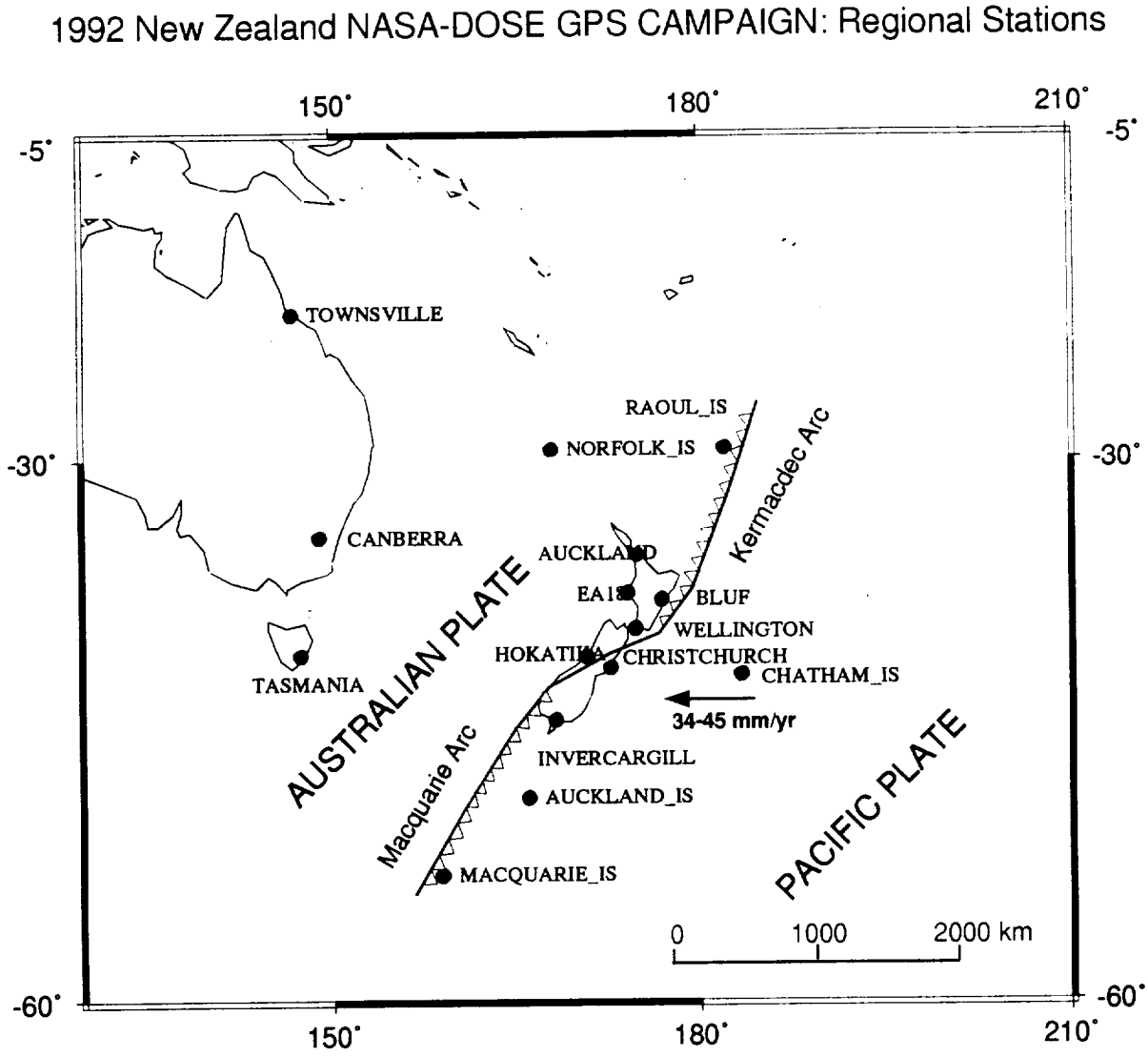


Figure 1. Map of New Zealand 1992 DOSE GPS stations for Phase A and regional GPS tracking stations in Australia. The Australian/Pacific plate boundary is shown schematically in the vicinity of New Zealand. The sawtooth pattern on the boundary indicates the down dip direction of subduction along the Kermadec and Macquarie Arcs. A representative plate velocity vector is shown for Chatham Island (relative to a fixed Australian plate). The estimate from NUVEL 1 is 34 mm/yr and from PO71 is 45 mm/yr.

Table 1: Phase A GPS Sites

Site Number	Site Name	Site Location	Receiver Type	Agency	Tectonic Plate
1334	XVII Whanga-paraoa	Auckland, NZ	Turborogue	DOSLI	AUS
1420	Mt. Greenland	Hokatika, NZ	Turborogue	DOSLI	AUS
5501	Hephy House 1	Wellington, NZ	Trimble 4000 SST	DOSLI (CIGNET)	AUS
5502	Hephy House 2	Wellington, NZ	Turborogue	DOSLI	AUS
5503	Waitangi	Chatham Is. NZ	Turborogue	UNAVCO/ IGNS	PAC
5504	CHAT-OIT S026339	Chatham Is. NZ	Turborogue	UNAVCO/ IGNS	PAC
5505	Astro Pillar	Chatham Is. NZ	Turborogue	IGNS	PAC
5506	E519	Norfolk Is. AUS	Turborogue	UNAVCO	AUS
5507	New Site*	Auckland Is. Group, NZ	Trimble 4000SST	IGNS	PAC
5508	Windsor Castle	Christchurch, NZ	Turborogue	DOSLI	PAC
5509	Three Sisters, Bluff	Invercargill, NZ	Turborogue	DOSLI	PAC
	New Site*	Raoul Is. NZ	Ashtech	DOSLI	AUS
	New Site	Macquarie Is. AUS	Ashtech or Trimble**	AUSLIG	PAC
1501	Bluff Hill#3	Napier, NZ	Turborogue	VUW	AUS
2404	EA18	New Plymouth, NZ	Turborogue	IGNS	AUS

* Sites observed outside main campaign time period
** Receiver type not confirmed yet

Table of additional tracking sites

Table 2: Selected Regional ContinuousTracking Sites

Site Name	Location	Receiver	Agency	Tectonic Plate
YAR1	Yarragadee, AUS	Rogue	JPL	AUS
TAS1	Tasmania, AUS	Minimac 2816AT	CIGNET	AUS
TOWN	Townsville, AUS	Trimble 4000 SST	CIGNET	AUS
DS40	Canberra, AUS	Rogue	JPL	AUS
KOKR	Kokee Park, USA	Rogue	JPL	PAC
USUD	Usuda, JAPAN	Rogue	JPL	EURA
MCMU	McMurdo Base Antarctica	Rogue	Univ. Texas	ANTA
TAIW	Taiwan	Rogue	IESAS	EURA

Field Program - Phase A

In order to obtain the highest possible precision over the long-baselines of the Phase A "megameter" survey, we adopted a conservative site observation plan. We planned to track for at least 9 days at the key sites. This long tracking period was selected to provide higher precision by increasing the number of observations and averaging unmodeled errors. The large number of days also helps to reduce the chance that external problems, such as satellite or tracking network problems or receiver/setup problems, would jeopardize the project. As it turned out, there were problems with the global tracking network at most Rogue receiver sites when anti-spoofing (A/S) was turned on. The Rogue receivers had a software problem which resulted in a loss of precision in the L2 phase values. Unfortunately, due to an unscheduled A/S test by the Air Force, A/S went on for two extra days resulting in A/S being on for a total of 4 (rather than 2) out of the 9 days of the Phase A survey. Although our Turborogue receivers were not significantly affected, the majority of the global Rogue sites had the software problem, described above. We will be investigating to what extent this will affect the precision of the post-fit orbits and of our results.

Comments about Phase A stations

Chatham Island (NZ)

This is one of the key sites of the survey as it is clearly away from the plate boundary and has some of the largest differences between plate models. Given the logistical constraints, two receivers were sent to the island. A new survey mark (with 3 reference marks) was installed by DOSLI at the meteorological station and it was surveyed into the local survey network using conventional survey equipment. One of the GPS receivers was run at this site for 9 days. Two other sites (Astro and Airport) were observed with the other receiver for 4 days each. These sites had been surveyed for 1 and 3 days using a Trimble 4000 SST in January 1990 so in addition to providing reference points and site redundancies, there is the possibility of comparing new with old surveys.

Norfolk Island (AUS)

Survey mark is set into a concrete block and has 3 reference marks and has been surveyed conventionally. The station was observed for 9 days with GPS during this campaign.

Invercargill, Christchurch, Hokitika, Auckland (NZ)

Invercargill and Christchurch are new marks installed by DOSLI. They will be tied into the local survey network. Hokitika is an existing trigonometric mark. These three stations were operated for both phase A and B for total of 22 days.Auckland was run for 9 days during phase A.

Auckland Islands (NZ)

This site was occupied for 2.5 days immediately after the phase B study. A new mark was installed on Enderby Island by D. McKnight of IGNS and a Trimble 4000 SST receiver was used. This occupation was one of opportunity as Dr. Mcknight was already going to the island on a NZ Ministry of Agriculture and Fisheries Vessel to make magnetic observations. This site replaces for the time being the proposed Campbell Island and Antipodes Island sites which could not be reached for this campaign.

Wellington (NZ)

DOSLI operates a Trimble 4000 SST receiver on the roof of their Heaphy House office in downtown Wellington. This receiver is operated continuously as part of the CIGNET tracking network and data are collected by the U.S. National Geodetic Survey on a daily basis. The antenna is mounted on a galvanized steel pipe known as GPS Pillar. A Turborogue receiver was run at a reference point on the roof for the duration of the NZ DOSE campaign. Just prior to the start of Phase A, a Trimble 4000 SST was used to observe the reference point in order to ensure a high precision tie without antenna mixing problems.

Raoul Island (NZ)

DOSLI made a complete survey of the island in March 1991 using Ashtech receivers. One receiver was operated for 20 days at the same site and should yield a high precision solution. The tie to North Island will be to the CIGNET Trimble 4000 SST at Wellington. We have not yet obtained the data from this site.

Macquarie Island (AUS)

GPS observations were to be made by an Australian survey team from AUSLIG as part of a large scale survey they are conducting in Australia and Antarctica in November - January 1992. We know that GPS observations were made during our experiment, but we have not yet obtained the data from AUSLIG or further details.

Napier and New Plymouth (NZ)

These sites span the central North Island and were first occupied for a few days in January 1990 along with Wellington and Chatham Island and were observed in Dec 1990 and Dec 1991 as part of the Taupo Volcanic Zone GPS surveys we conducted. They were observed for two days during Phase A in order to provide a consistent network for comparisons with the older surveys and to provide additional data on the extent of plate boundary zone deformation across New Zealand.

Data Translation

The bulk of the data from the Turborogue receivers were collected in "Turbobinary" format. For our processing, we need to have RINEX exchange format, an ASCII format. Currently the translation from Turbobinary to RINEX involves two steps. The first step is to convert Turbobinary to "STD" format, then the STD file is converted to RINEX. The programs to do this reside at JPL and are currently not portable. We are working with Tom Lockhart and Tom Meehan at JPL to ensure that the data are converted correctly and to archive the raw and RINEX data and logsheets. According to Tom Meehan, there are two known problems with the Version 2.3 raw data files that we collected. The first problem is that a half-cycle slip can occur in the L1 phase data when Anti-Spoofing is turned on and the receiver switches to cross-correlation tracking mode (this happened twice during our campaign). As half-cycle slips are not expected from this receiver, this makes processing of the data more difficult. This problem was corrected in later versions of the Turborogue operating system. The second problem is that occasionally the code data has a 9 cycle offset. This problem makes it difficult to use pre-processing programs such as Turboedit which we use to automatically clean the data files. Our understanding is that both problems can be corrected for in the conversion from binary to RINEX and we are working with JPL to see that these corrections are implemented.

In-Field Processing

For the first few days of Phase A, data were down-loaded in both Turbobinary and RINEX formats so that the RINEX files could be processed. All RINEX files were processed using UNAVCO's QC quality checking program. This program checks for receiver noise characteristics, frequency of cycle slips and overall tracking performance. With this program, we could ensure that all the receivers were operating properly.

In addition to QC, we processed the first few days of Phase A data using the Bernese software which we installed on a SUN system at Victoria University. This processing offered a final assurance that the data were good, though solution repeatability was only at approximately 0.5 ppm due to limitations of using current broadcast orbits, particularly over the long baselines of this study. We did not collect additional RINEX files in the field as the download time of the receiver in RINEX format for the long, 22 hour, sessions proved to be too time consuming (over 30 min/file) and since the RINEX files did not fit on a single floppy and there was no mechanism for splitting the files across disks.

All Turbobinary files were transferred from PC diskette to 8 mm tape on a SUN workstation. One copy of the diskettes and logsheets was left with IGNS in New Zealand and one copy was brought back to UNAVCO. Data are being archived at UNAVCO and logsheets are being scanned prior to submittal to the JPL archive.

Orbit Determinations

The precision requirements of this experiment are quite high. After two years, the predicted differences in length between the plate models will be at most 2-3 cm. The accuracy of the orbits used for analysis must be quite high as well. We will evaluate orbits from a number of possible sources (Table 3).

Table 3: Possible sources of improved orbits

1. JPL (JPL Global Rogue and Turborogue data only)
2. Scripps PGGA (JPL Global and S. Calif. Rogue and Turborogue data, others upon request)
3. NGS (CIGNET and JPL Global, Northern Hemisphere only)
4. DMA (DMA and Air Force Tracking data)
5. Berne, CODE Orbits, (CIGNET and JPL data)
6. compute our own orbits using available tracking data

The accuracy of the orbits may be variable during the campaign due to problems with tracking stations and implementation of A/S on six days of the survey. We will request the groups creating the orbits to include some of our data to enhance the accuracy of the orbits.

1993 Activities

We expect the translation, processing and analysis of data as well as evaluation of orbits to be the bulk of the 1993 project activity. There is a wide mix of receiver data sets and the time period of observations from the various sites encompasses many months and the tracking data is variable. We will need to integrate these data sets together and deal with data outages. We will work with JPL on data translation and archival issues.

APPENDIX I.

KINEMATICS OF THE NEW ZEALAND PLATE BOUNDARY

PROJECT SUMMARY

R.I. Walcott

OBJECTIVES - PHASE A

One of the great scientific achievments of recent time is the determination of the relative velocities of the tectonic plates given in publications by Minster and Jordan in 1978; Chase, also in 1978; and, most recently by DeMets and others in 1990. The relative velocity of any pair of plates is completely described by a vector referred to as the euler vector of the plate pair. The euler vectors listed in the above publications generalise a vast amount of data from plate boundaries all over the earth. Convergent and transform boundaries have supplied some information based on observations of the slip vectors of earthquakes but by far the bulk of the useful information comes from spreading ridges. The Pacific/Australian Plate boundary however has not provided useful information for the most part because of its manifest complexity involving over most of its length back-arc spreading and oblique subduction. Consequently the euler vector predicted, for example, by the NUVEL-1 model (DeMets et al, 1990) for this plate boundary is a vector resultant of motions across adjacent plate boundaries, and in particular those of the Antarctic Plate.

A direct determination of the euler vector for the Pacific/Australian Plate boundary is, therefore, important in global plate kinematics; it will provide an independent check on kinematic models; it will provide information of a fundamental kind for the whole of the Pacific/Australian plate boundary and not just the New Zealand part; and it will be a substantial move toward the direct, geodetic measurement of plate motions, world-wide.

New Zealand lies close to the pole of the euler vector that describes the relative motion of the Pacific and Australian Plates. This means that in the vicinity of New Zealand changes in azimuth and length of lines that cross the boundary vary rapidly with position and orientation. It is thus a particularly good location to determine the euler vector by GPS survey techniques. Annual changes in line length predicted by the NUVEL-1 euler vector vary between +38 and -34 mm. A comparison of line length changes with the Chase (1978) euler vector, the pole of which is located some 7° longitude further west and with a rotation rate 5% faster, shows differences of around +/-11 mm/y. Differences of this size are about the expected uncertainty (95%) in relative network positions on 1000 km baselines determined by modern GPS survey techniques so that with observations repeated over a 3 or 4 year period we can expect to be able to determine the euler vector with a formal precision comparable to that claimed for NUVEL-1, i.e. about 2° in position and about 5% in rate.

In principle, the euler vector can be determined by measurement of the relative velocity of only two points - one on the Pacific and one on the Australian

Plate - at say Christchurch and Hokitika, for example. But greater redundancy of data is desirable in order to estimate errors and it is also desirable to spread the stations to estimate the stability of the plates over the time interval of the observations. Although Hokitika and Christchurch are likely to lie on their respective plates - that is, beyond the plate boundary zone, and the zone of active, shallow seismicity - it is still necessary to establish their stability relative to stations about 1000 km from the plate boundary. For both of these reasons the proposed network establishes stations in a network of approximately 1000 km baselines.

OBJECTIVES - PHASE B

The boundary between the Australian and Pacific Plates runs through New Zealand with eastern South Island on the Pacific Plate and western New Zealand on the Australian Plate. This plate boundary zone is narrower and more directly accessible than almost any other in continental parts of the world. Over the last 20 years knowledge of the rates of deformation within the New Zealand plate boundary determined from sparse geodetic data has thrown light on the mechanisms of deformation of continental crust. The coverage is, however, inadequate to answer questions of such major importance as where the relative motion of the plates is actually located within the plate boundary zone. GPS techniques now permit the measurement of strain giving more precision and greater coverage than before.

To identify the location of the high strain rates associated with the plate boundary, some 40 stations are to be occupied between Hokitika and Christchurch over Arthurs Pass during this phase of the project - at about 2.5 km intervals from the Alpine fault to Arthurs Pass and at 5 to 10 km intervals elsewhere. These stations will be located in points of easiest access for reoccupation in 1995/96 to determine the strain rate. To determine the rate and stability in time of the strain, reobservation of a 1978 Earth Deformation Survey between Hokitika and Christchurch made by DOSLI and of a survey made across the Southern Alps about 110 years ago by Roberts may be undertaken. Only some of the original stations of this older survey still exist, but because of the long time base resurvey of the remnant is important.

OBJECTIVES - PHASE C

THE NOVEMBER 1992 WELLINGTON GPS SURVEY

All that is known about the sensitivity of the present-day crustal strain field to major earthquake faults in the Wellington region is contained in the appended article, reprinted from the Bulletin of the NZ National Society of Earthquake Engineering. This article shows that while there appears to be a concentration of strain about the Wellington fault, this interpretation is equivocal because the same measuring experiments have not been done both across and between the major faults. The November 1992 Wellington GPS survey is the first stage of a project designed to resolve this problem.

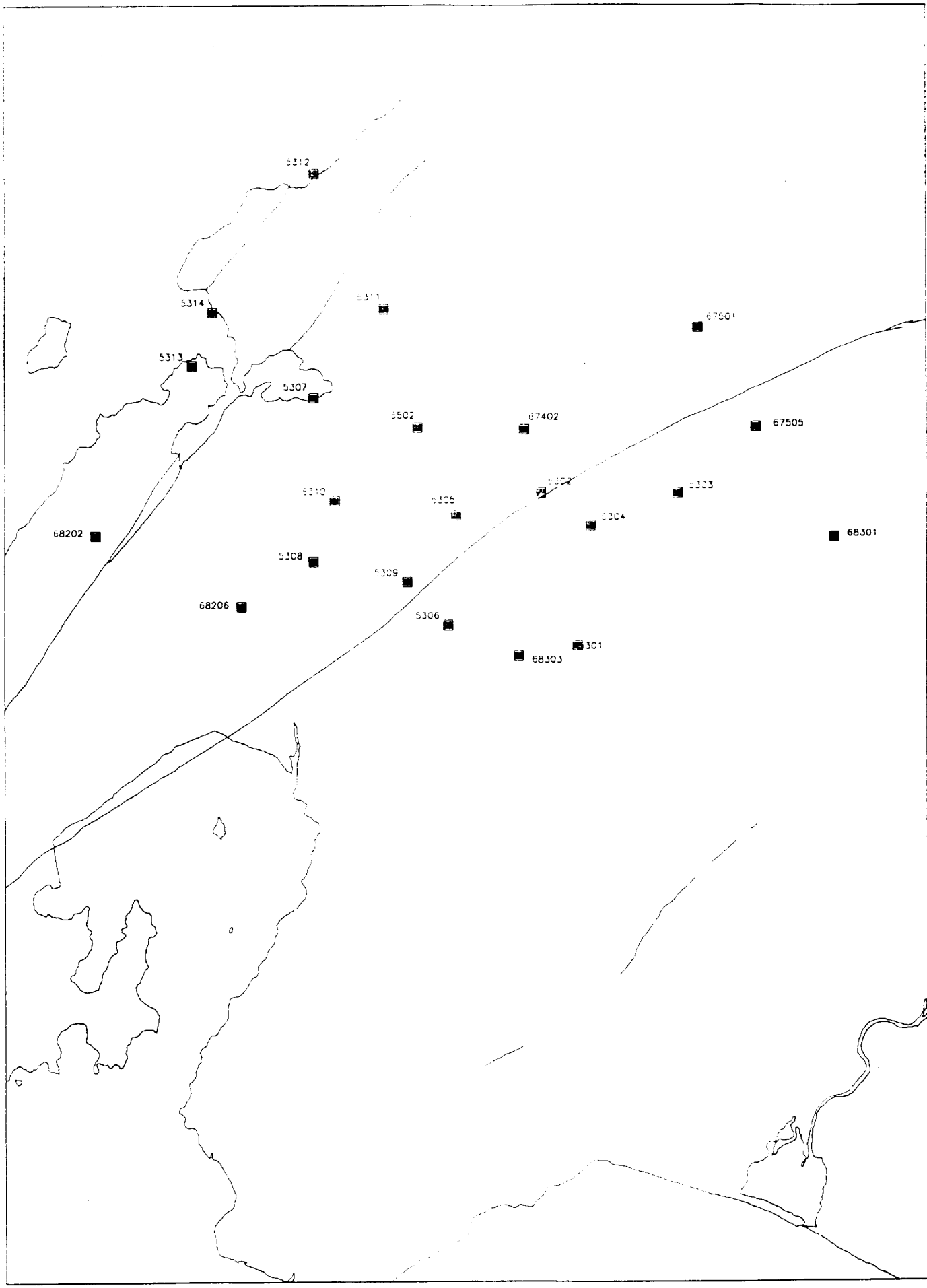
The location of the array of survey points has been chosen so that ultimately it will be possible to obtain strain both across and between the major through-going active Pukerua, Ohariu, Wellington, and Wairarapa faults. Station locations should be reasonably accessible, but also likely to survive for many decades. Stations ought to be limited to a number that can practicably be surveyed with existing and future resources. There must be enough stations between major faults that meaningful crustal strain can be estimated above the background of local surficial station instabilities. The spacing between stations needs to be large enough that strain originating from stresses at seismogenic depths can be sampled. For GPS to be the appropriate measuring technology, the station spacing has to be also be large enough that distance-independent measurement errors do not dominate the strain estimates. Results from our station spacing of 3-5 km will supplement those from the smaller scale experiments at Te Marua (5 m) and Totara Park (150 m), and the larger scale surveys of the Hutt Valley chain of triangulation stations (10 km) and the Wellington region first order network (30 km).

Geodetic GPS observations measure the phase of the GPS carrier signal to achieve sub-centimetre precision, in contrast to the navigational observations which use coded modulations to achieve dekametre precision. Geodetic measurements must therefore be post-processed to allow for receiver and satellite clock errors, ionospheric and tropospheric effects on the velocity of electromagnetic wave propagation, and improvements to the broadcast satellite orbits which are only predictions. We have recently received a Lotteries Board Grant to purchase computing hardware and software to do this post-processing ourselves. The results will be three-dimensional vectors, and their variance-covariance matrix, between the positions of the observed stations. Elegant deformation analysis methods allow us to compare these with other GPS surveys, or with triangulation measurements of horizontal angles if a gravitational direction is derived or assumed at each station. The comparison allows us to estimate the components of the strain tensor. With this tensor, which provides a complete description of the deformation, the question of the influence of the faults can be addressed.

The Wellington survey will also provide a training opportunity for observers involved in other GPS projects of this summer's field campaign. These projects are dedicated to measuring the relative motions of the Pacific and Australian tectonic plates over a megametre scale network, and measuring deformation within the simplest part of the deforming plate boundary zone, across the Alpine fault. The rationale of those projects is detailed in the relevant observers' folders.

Thank you for your participation. May your plumbing be precise.

Des Darby
16 November 1992



Bull. of the N.Z. Nat. Soc. Earthquake Engineering
vol 22, No1, pp., 1989

Is strain concentrating about the Wellington Fault?

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Deformation monitoring arrays with spatial apertures extending over three orders of magnitude provide evidence for a concentration of strain about the Wellington Fault. Nowhere else in New Zealand is this type of comparison possible.

The smallest of these arrays is the Te Marua strainmeter of 5 m aperture. It consists of an array of steel rods, described in detail by Brown and Wood (1983). The method of data analysis and possible systematic instrumental problems are discussed by Darby and Perrin (1986). The remaining arrays are survey networks with apertures from 130 m to 28 km (see figure). Standard analysis methods were used and the results obtained by R. Williams (pers. com.) are similar to those reported by others at this workshop. The following table summarises results from all the arrays.

Array	Aperture (m)	Period	Surveys	df[1]	Max shear[2] ppm/yr[4]	Azimuth[3] deg[4]
Te Marua	5	1982-88	27	92	5.4 (1.6)	139(7)
Totara Park	130	1974-85	11	255	1.31(0.66)	140(10)
Wgtn Quad	10000	1929-69	2	12	0.47(0.14)	102(15)
"	"	1969-83	8	66	0.67(0.42)	96(25)
HV Chain	10000	1972-79	5	147	0.44(0.62)	112(47)
Wgtn Region	28000	1929-81	2	51	0.42(0.12)	112(8)

[1] Degrees of freedom in strain estimation
[2] Engineering shear
[3] Azimuth of relative contraction
[4] Parentheses enclose 95% confidence half-widths from small error formulae

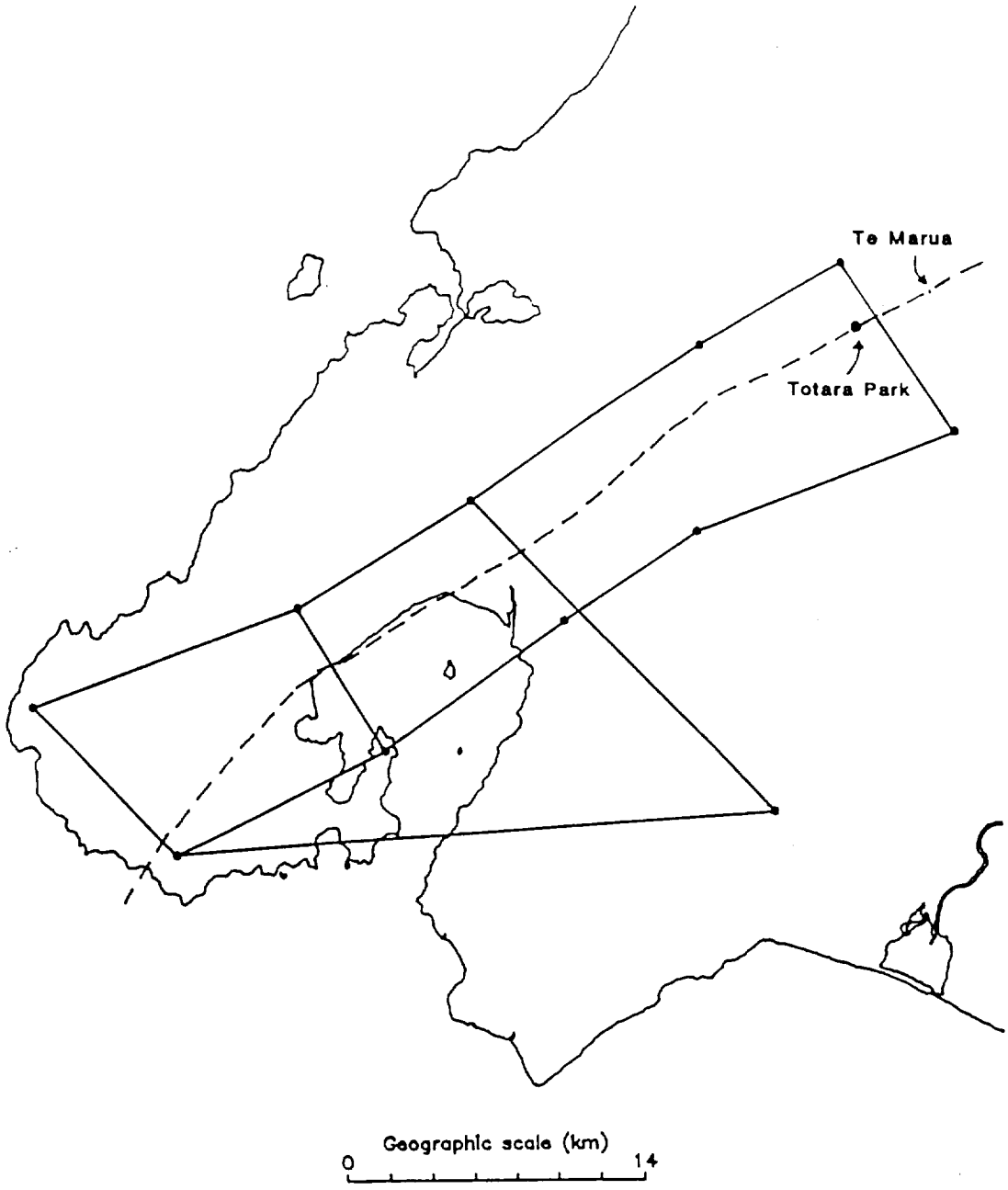
The Te Marua result may be affected by instrumental problems, but confidence in it is enhanced by the similarity of its orientation to that at Totara Park. Deceptively high strain rates can arise from a single strain event, or a systematic error mimicking strain, between two surveys being divided by a short time period. This cannot happen here because of the large numbers of surveys done within the shorter time periods. Conversely, the smaller confidence intervals associated with the results from only two surveys, over the longer time periods, may arise from the inability of those data to contain departures from the uniform strain rate model.

The better determined strain orientations show relative contraction at respectively 80 deg and 60 deg to the fault strikes at Te Marua and Wellington. The displacement rate across the Te Marua array is too small (of the order of tens of microns/yr) to be called creep in the usual sense of fault creep. The strain rate varies approximately as the aperture raised to the power of -0.3 so that, for example, a tenfold increase in aperture corresponds to a halving of the strain rate. This variation cannot be due to slow fault creep confined to the gouge zone and an immediate interpretation is that the regional strain is greater nearer the Wellington Fault than farther from it. The data give no information about what proportion of the variation may be plastic (irrecoverable) or elastic (recoverable) strain. Furthermore, the possibility of strain inhomogeneities independent of faulting has not been tested; that is, no 5 m or 130 m arrays lie elsewhere within the larger arrays. Lateral variation of rigidity and plasticity of surface materials must be taken into account before these results can be interpreted in terms of stress.

References

Brown, I.R., Wood, P.R. 1983: Strain measurement across the Wellington fault at Te Marua. In: Proceedings, Third South Pacific Regional Conference on Earthquake Engineering. Wellington, The New Zealand National Society for Earthquake Engineering: 509-518.

Darby, D.J., Perrin, N.D. 1986: Mechanical strain gauge measurements at Te Marua. Bulletin of the N.Z. National Society for Earthquake Engineering 19(2): 104-110.



Distribution of arrays with respect to the Wellington Fault. The locations of the Te Marua and Totara Park arrays are as shown, the Wellington Quadrilateral is the southwestern portion of the northeast trending Hutt Valley Chain, and the larger array to the south is the Wellington Region array. The trace of the Wellington Fault is indicated by the dashed line.

APPENDIX II.

NZ PLATE BOUNDARY KINEMATICS
1992 GPS CAMPAIGN

PROJECT PLAN
15 November 1992

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1. OBJECTIVES

a. To determine the Euler vector for Pacific/Australian plate motion using GPS (Phase A).

b. To investigate the distribution of deformation within the narrowest part of the plate boundary zone, in the central South Island (Phase B).

2. RECEIVERS

Twelve Turbo-Rogue and three Trimble 4000SST receivers are to be employed on the project. The availability of this number of receivers, and the timetable for access to offshore sites, has allowed the planning of an additional phase of work (C), concurrent with Phase A.

3. PHASE A

Eight principal stations will be occupied during Phase A. Five are in New Zealand and will be managed by the NZ Department of Survey and Land Information; these will be run for the entire project period (Phases A and B). The other Phase A sites are on Norfolk Island, Chatham Island, and a location in the Auckland Islands group (Enderby Island or Auckland Island). The Australian Surveying and Land Information Group will be operating a Trimble 4000SST at Macquarie Island at some time during the campaign.

The Phase A stations and occupation dates are:

1. Whangaparaoa Peninsula (Auckland)
   Turbo-Rogue: 26 November - 17 December

2. Christchurch
   Turbo-Rogue: 26 November - 17 December

3. Mt Greenland (Hokitika)
   Turbo-Rogue: 26 November - 17 December

4. Bluff
   Turbo-Rogue: 26 November - 17 December

5. E519, Norfolk Island
   Turbo-Rogue: 26 November - 5 December

6. Met enclosure, Chatham Island
   Turbo-Rogue: 26 November - 5 December

7. Auckland Islands
   Trimble: 13 December - 16 December (approx)

8. Wellington
   Turbo-Rogue: 26 November - 17 December

To allow connection to other marks (previously observed by GPS in 1989), 2 Turbo-Rogues will go to Chatham Islands.

Logistical arrangements for the sites are detailed in Appendix A. The stations are listed in Appendix E.

The base site for Phases A and C is the Geology Department, Cotton Building, Victoria University of Wellington (Appendix A, Shipping). Phase A will be directed by Dick Walcott and Chuck Meertens.

4. PHASE B

Phase B will commence in Christchurch on Thursday 3 December, using all unassigned receivers from Phase A. The Turbo-Rogue receivers from Norfolk and Chatham Islands will be available from Sunday 6 December. A Trimble will be consigned to the Auckland Islands from that date.

About 40 stations will be occupied in a transect across the Southern Alps between Christchurch and Hokitika using 7 Turbo-Rogue and 2 Trimble receivers. The last day of observation is Thursday 17 December. The Phase B stations (subject to reconnaissance) are listed in Appendix E.

Phase B will be directed by John Beavan and Des Darby.

5. PHASE C

Phase A will not fully occupy all of the receivers that are to be shipped to New Zealand. There are 4 Turbo-Rogues and 3 Trimbles available for additional observations - once training has finished in Wellington and before the equipment must be transferred to Christchurch for Phase B.

The VUW, UNAVCO, and IGNS investigators have made GPS measurements

from stations at New Plymouth, Napier, and Wairakei in 1989, 1990, and 1991. The New Plymouth and Napier stations will be re-occupied with Turbo-Rogues for 2-3 days during Phase C. The remaining receivers (2 Turbo-Rogues and 3 Trimbles) will be deployed on a number of sites in the Wellington Region. There are many worthwhile candidate stations which have a previous history of geodetic observations for tectonic studies (Appendix E).

Phase C will be directed by Des Darby and Jim Ansell (VUW).

6. TIMETABLE

A two-page project timetable has been prepared by Graeme Blick, UNAVCO, and was faxed to New Zealand on 13 October 1992. It should be appended to any paper copy of this plan.

7. TRAINING

Training of most operators will occur at Victoria University in the Geology Department. It is a relatively quiet time of year. Receivers will be located in a locked lab with plenty of space on the ground floor adjacent to a loading bay, an electronics facility, battery store (and charging) and also the permanently occupied building security office. There is easy access outside to grassed areas. The DOSLI, VUW and IGNS personnel will be trained on the 23rd and 24th of November. University hostel accommodation for DOSLI personnel can be arranged if desired.

Training of the Otago operators will occur at Christchurch at the commencement of Phase B.

8. APPENDICES

APPENDIX A. LOGISTICS

SHIPPING

Eleven Turbo Rogues will be sent to NZ from JPL on 17 November under one carnet. Three Trimbles (2 UNAVCO and 1 JPL) will be sent from UNAVCO, Boulder, on 16 November under two carnets. The JPL receiver will be on its own carnet so that it can go to the Auckland Islands and can be returned to Boulder at a later date than the other equipment.

One Turbo Rogue will be sent to Norfolk Island as hand carry with Chris Rocken on its own carnet. At the end of Phase A it will be transferred to Christchurch, then returned to JPL.

These shipping dates will ensure that all equipment is in NZ by Monday 23rd and hopefully Friday 20th November. Shipping dates for equipment back to JPL/UNAVCO are set for 18 or 19 December with a fall back date of 21 December.

The shipping address for Phase A is:

Prof. R.I. Walcott
Geology Department, Cotton Building
Victoria University of Wellington
Kelburn Parade, Wellington
Contact phone 471-5392 or 471-5345 (Geology Office)

The shipping address for Phase B is:

Dr. D. McKnight, Geomagnetic Observatory
Institute of Geological and Nuclear Sciences
Ilam Research Centre
31 Creyke Road, Ilam
Christchurch
Contact phone 351-6019 or fax 351-9923

NORFOLK ISLAND (Chris Rocken)

The station to be occupied is E519, in the grounds of the Bureau of Meteorology Office, 0.5km from the airport terminal. Site details have been supplied by the Australian Surveying and Land Information Group. Permission to use the mark has been obtained from the Bureau of Meteorology in Sydney. The receiver may be housed and powered in the Bureau's office building. The Bureau Officer in Charge on Norfolk is Ian Moran.

Note that Norfolk Island is Australian territory and there is the usual customs barrier between Norfolk and New Zealand. The Turbo-Rogue going to Norfolk will therefore need to go through Customs both going from NZ to Norfolk and on its return Norfolk to New Zealand. It will be necessary therefore to have that Turbo-Rogue on a separate carnet with sufficient pages to allow two entries to NZ and one entry to Australia (and presumably one to the US on its return). The Turbo-Rogue will be sent to Christchurch by Chris Rocken on Dec 5th from Auckland at the completion of the Norfolk operating schedule.

CHATHAM ISLAND (Chuck Meertens and Andrew Carman)

Three sites are to be observed on Chatham Island. Two Turbo-Rogue receivers are required.

a. A new site, being the main mark for Phase A. Observations from 25 November - 5 December.

b. A site near the airport, observed with GPS by the VUW/Dallas group in 1989. 2-3 days of observations.

c. The astro pillar site near Waitangi. First used for astronomical latitude and longitude observations in 1924 and also observed by the VUW/Dallas group with GPS in 1989. 1-2 days of observations.

Accommodation at the Chatham Lodge is booked. Utility vehicles are available for hire. Two surveyors from the Wellington District Office of the Department of Survey and Land Information will be on the Chathams from 17 November - 1 December. The main GPS mark will be sited and installed by the DOSLI surveyors in the week 17-24 November, using premixed dry concrete already shipped. The mark is planned to be in or near the NZ Meteorological Service enclosure at Waitangi. The local observer is Mr Vaughan Legros (Phone and Fax 03 305 0054). Four 11-plate marine batteries and a 4 amp battery charger have already been shipped to Vaughan. (It is intended that the batteries be left behind at the end of the survey). Solar charging panels are desirable for both Rogues at the Chathams.

Two Turbo-Rogues will be be packaged with tripod and tribrach each

(but not battery) for shipment as accompanying baggage on the flight to the Chathams.

Schedule:

(1) Tuesday 24 November (Andrew Carman and Chuck Meertens to Chathams)

Wgtn-ChCh	NZ421	11.30	12.15
ChCh-Chathams	NM2290	12.55	16.00

(2) Saturday 28 November (Meertens return)

Chathams-ChCh	NM2691	17.00	19.15
ChCh-Wgtn	NZ484	19.45	20.30

(3) Saturday 5 December (Andrew Carman return to Christchurch)

Chathams-ChCh	NM2691	17.00	19.15

Excess baggage in NZ - $20/piece
Excess baggage to/from Chathams $5/kg

AUCKLAND ISLANDS (Don McKnight)

Permission to visit the Auckland Islands has been granted by the NZ Department of Conservation (Permit No. 92/1/3).

Transport to the Auckland Islands will be by way of the NZ Ministry of Agriculture and Fisheries research vessel "Tangaroa", departing from Dunedin on the evening of 7 December and returning to Wellington on 23 December. The ship will offload Don McKnight (and four Department of Conservation seal researchers) at the Auckland Islands (Enderby Island) within approximately 7 days. It will return 3 full days later to collect McKnight only.

Don McKnight will be responsible for selecting and monumenting a suitable site. An existing Hydrographic Service mark may be suitable. The Trimble receiver will be programmed to run continuously once set up. In addition to the GPS observations, McKnight will be carrying out his own programme of magnetic observations on the Islands during the period ashore.

NZ FIXED SITES

The fixed station receivers may be couriered from Wellington to Auckland, Hokitika, Christchurch and Invercargill DOSLI District Offices. Depending on their weight and cost of shipment the receivers may be sent as accompanying baggage with the operators for those stations when they return to their District Offices on Wednesday 25th November from the training session in Wellington.

The addresses and local contacts at the Department of Survey and Land Information are:

AUCKLAND: Telephone 09 377 1899
Fax 09 307 1025

Postal Address: PO Box 5249
Auckland

Street Address:	7th Floor AA Centre 99 Albert Street Auckland
Contact:	Colin Wratt
WELLINGTON:	Telephone 04 471 0380 Fax 04 495 8450
Postal Address:	CPO Box 170 Wellington
Street Address:	Heaphy House 103-115 Thorndon Quay Wellington
Contact:	Glen Rowe
CHRISTCHURCH:	Telephone 03 789 799 Fax 03 666 422
Postal Address:	Private Bag Christchurch
Street Address:	3rd Floor State Insurance Building 115 Worcester Street Christchurch
Contact:	Brian Andersen
HOKITIKA:	Telephone 03 755 8586 Fax 03 755 8808
Postal Address:	PO Box 123 Hokitika
Street Address:	2nd Floor Seddon House Sewell Street Hokitika
Contact:	Tony Fraser
INVERCARGILL:	Telephone 03 218 7334 Fax 03 214 4763
Postal Address:	PO Box 826 Invercargill
Street Address:	2nd Floor Henderson House 93 Kelvin Street Invercargill
Contact:	Craig Thompson

PHASE A OBSERVING SCHEDULE

(a) Stations at: Auckland (XVII Whangaparaoa), Wellington, Hokitika (Mt Greenland), Christchurch, and Bluff will operate at least 22.5 hrs a day beginning 22.30 UTC Wednesday 25th November and ending 21.00 UTC on Thursday 17th December.

(b) Stations at: Norfolk Island (E519) and Chatham Island will operate on the same daily schedule as (a), beginning at 22.30 UTC Wednesday 25th November and ending 21.00 UTC on Friday 4th December.

(c) Station at the Auckland Islands will operate 24 hrs a day approximately beginning Sunday December 13th and ending Thursday December 17th.

All receiver logging will be at 30sec intervals.

PHASE B

The initial base for Phase B will be at the IGNS Geomagnetic Observatory, Ilam Research Centre, in Christchurch (shipping address as given above). Equipment will be transported by vehicle from Wellington to Christchurch. Four vehicles (including two vans) and a large trailer are available for this.

The base will be relocated west towards Hokitika as Phase B observations proceed. In the first instance, arrangements have already been made for use of the University of Canterbury field station at Cass, immediately east of Arthur's Pass.

Reconnaissance for Phase B is currently underway by Chris Pearson and Peter Wood.

APPENDIX B. EQUIPMENT

UNITED STATES EQUIPMENT

- All of the GPS receivers, and their ancillary equipment, excluding tripods and batteries. (A tripod may be required on Norfolk Island).

- All documentation originals, except for station access notes. (These can be copied and assembled into field folders in NZ). Maps will be supplied by NZ.

- A number of portable PCs. (20 MB hard disk and 1.44 MB high density floppy drive required).

- All floppy disks for data archiving.

NEW ZEALAND EQUIPMENT

- Tripods. (IGNS will supply at least 10 for Phases A-C. DOSLI District Offices will supply their own tripods. Otago will supply at least 4 tripods for Phase C).

- Batteries and Chargers. DOSLI District Offices will supply their own for Phase A sites. IGNS and VUW will supply the remainder. (Four 38 Ah batteries have been purchased in NZ on behalf of Lamont).

- Theodolites. For plumbing antenna brackets on unremovable beacons.

- Setup pegs, tools, and miscellaneous equipment.

- PCs. IGNS will supply at least 2.
  VUW ?
  Otago?

- Sun Workstation system. (VUW ?)

- Vehicles (see Appendix D)

- Cell Phones. IGNS will supply at least two, probably three.

- Radios. IGNS vehicles have VHF radios. A number of portable sets will also be supplied.

APPENDIX C. PERSONNEL

UNITED STATES PERSONNEL:

LAMONT-DOHERTY GEOLOGICAL OBSERVATORY:

John Beavan
Ted Koczynski

UNAVCO:

Chuck Meertens
Chris Rocken

NEW ZEALAND PERSONNEL:

VICTORIA UNIVERSITY OF WELLINGTON:

Dick Walcott, Professor of Geology
Home Address: 24 Mahoe St
Eastbourne
Wellington Phone 04 562 8040
Next of Kin: Wife, Genevieve, as above
Work address: Department of Geology
Victoria University of Wellington
PO Box 600
Wellington Phone 04 471 5392
Secty Phone 04 471 5345
FAX 04 495 5186
University switchboard 04 472 1000

John Taber, Post-Doctoral Fellow, Geophysics
Home address: 26 Fox St
Ngaio
Wellington Phone 04 479 1407
Next of Kin: Parents,
Jospeh J. Taber
700 Leroy Place
Socorro
New Mexico 87801 Phone 505-835-1846

Work address: Institute of Geophysics
Victoria University of Wellington
PO Box 600,
Wellington Phone 04 472 1000/8964
Emergency contact: Kathy Power
159 Onslow Rd
Khandallah
Wellington Phone 04 479 3602

Ray Dibble, Reader in Geophysics (retired)
Home address: 81 Oriel Ave
Tawa
Wellington Phone 04 232 7631
Next of Kin: Wife, Thelma, as above

Miles Dunkin, Research Assistant
Home address: 7 Roxburgh St
Mt Victoria
Wellington Phone 04 384 3444
Next of Kin: Mother, Daphne Dunkin
Emergency contact: Anna Clarke
70 Hawker St
Wellington Phone 04 384 3607

Steve Langridge, Research Assistant
Home address: 6A Landcross St
Kelburn
Wellington Phone 04 475 7593
Next of Kin: R.E.T. Langridge
1 Dryden St
Gisborne Phone 086 76463

OTAGO UNIVERSITY:

Chris Pearson, Post-Doctoral Fellow, Geophysics
Home address: 182 Signal Rd
Dunedin Phone 03 473 0441
Next of Kin: Wife, Kathy Woodrow, as above

Albert Chong, Lecturer, Department of Surveying
Home address: 55 Glendining Ave
Dunedin Phone 03 473 8171
Next of Kin: Wife, Lay-Choo Chong, as above

Mark Henderson, Grad student, Research Assistant
Home address: 1056 George St
Dunedin Phone 03 473 8860
Next of Kin: Parents, Henderson
24 Pukatera St
Timaru Phone 03 686 1291

Karen Watson, Surveying Student, Research Assistant
Home address: 2/114 Harbour Tce
Dunedin Phone 03 477 3566
Next of Kin: Parents, T G and V W Watson
Walker St East, RD2
Katikati Phone 07 549 0909

Christopher A. Spencer, Surveying Student, Research Assistant
Home address: 18 Brownville Crs.
Maori Hill
Dunedin Phone 03 464 0936
Next of Kin: Wife, Jerry O'Kelly, as above

DEPARTMENT OF SURVEY AND LAND INFORMATION:

Matt Oakes, Auckland

Glen Rowe, Wellington

Brian Andersen, Christchurch

Paul Lucas, Hokitika

Craig Thompson, Invercargill

INSTITUTE OF GEOLOGICAL AND NUCLEAR SCIENCES:

Des Darby, project co-investigator, field operator
Work address: Institute of Geological & Nuclear Sciences
PO Box 30-368
Lower Hutt srlndjd@lhn.gns.cri.nz
Next of Kin: Wife, Magda Darby
Phone 04 567 9331

Graeme Blick, logistics/field manager (JPL/UNAVCO)
Work address: UNAVCO/UCAR
PO Box 3000
Boulder
CO 80307-3000 blick@unavco.ucar.edu
Next of Kin: Wife, Christine Blick
Phone +1 303 494 3584

Roger Williams, logistics/field manager (IGNS)
Work address: Institute of Geological & Nuclear Sciences
PO Box 30-368
Lower Hutt srlnrow@lhn.gns.cri.nz
Next of Kin: Wife, Mary Williams
Phone 04 478 4137

Andrew Carman, field operator (Chatham Islands)
Work address: Institute of Geological & Nuclear Sciences
PO Box 1320
Wellington srwgafc@mlg.gns.cri.nz
Next of Kin: Wife, Sally Carman
Phone 04 385 1107

Don McKnight, field operator (Auckland Islands)
Work address: Institute of Geological & Nuclear Sciences
Ilam Research Centre
PO Box 29-181
Christchurch
Next of Kin: Wife, Christine McKnight
Phone 03 332 0343

Peter Otway, field operator (Taupo)
Work address: Institute of Geological & Nuclear Sciences
Wairakei Research Centre
Private Bag 2000
Taupo
Next of Kin: Wife, Rosemary Otway
Phone 07 378 5901

Bradley Scott, field operator
Work address: Institute of Geological & Nuclear Sciences
Wairakei Research Centre
Private Bag 2000
Taupo
b.scott@lhn.gns.cri.nz
Next of Kin: Wife, Judy Scott
Phone 07 347 8953

Russ Van Dissen, field operator
Work address: Institute of Geological & Nuclear Sciences
PO Box 30-368
Lower Hutt
Next of Kin: Wife, Joanne Van Dissen
Phone 04 564 7368

Peter Wood, field operator/logistics (South Island)
Work address: Institute of Geological & Nuclear Sciences
PO Box 30-368
Lower Hutt
p.wood@lhn.gns.cri.nz
Next of Kin: Wife, Judy Wood
Phone 04 528 6722

APPENDIX D. VEHICLES

The following vehicles are available for use in NZ. DOSLI District Offices will supply their own transport.

1. Toyota Hilux 4WD double cab (IGNS)
   Phases A, B ,C

2. Toyota Landcruiser 4WD SWB (IGNS)
   Phases A, B ,C

3. Mitsubishi L300 van (VUW)
   Phases A, B ,C

4. Mitsubishi L300 van (VUW)
   Phases A, B ,C

5. Isuzu Trooper 4WD (IGNS)
   Phase B

6. Honda City car (IGNS)
   Phase B

7. Large trailer (IGNS)
   Phases A, B, C

8. 4WD Van (Otago)
   Phase B

9. 4WD ? (Canterbury)
   Phase B

10. LWB Landrover (VUW)
    Phase C

11. SWB Nissan Patrol (IGNS)
    Phase C

12. Mitsubishi Pajero/Isuzu Trooper 4WD (IGNS)
    Phase C

APPENDIX E. STATION LISTS

All stations are identified by a numeric code and a full name. The same numeric code will be used for both the "4-Char ID" and "Station ID #" of the NASA/JPL Site Information Report form. The existing First Order and EDS trig stations throughout New Zealand have already been numbered by IGNS, and computer datafiles of previous surveys have been constructed on that basis. Sites that are presently un-numbered are shown nnnn. Numbers will be assigned during reconnaissance.

PHASE A SITES: (11 sites)

1334	XVII Whangaparaoa
5508	Windsor Castle, Christchurch
1420	Mt Greenland, Hokitika
5509	Three Sisters, Bluff
5506	E519, Norfolk Islands
5503	New Name, Chatham Island
5504	CHAT - OIT SO26359, Chatham Island Airport
5505	Astro pillar, Chatham Island
5507	New Name, Auckland Islands
5501	Heaphy House
5502	Turbo-Rogue site in Wellington (BRANZ?)

PHASE B SITES: (46 sites)

The following is a list of stations expected to be occupied Dec 3rd to Dec 18th 1992. The list has been prepared from a map study only. It is subject to revision by the pre-campaign reconnaissance being carried out by Chris Pearson and Peter Wood.

1126	Mt Pleasant	498m	Road access, near microwave tower
1135	Cass Peak No2	255m	Road access, " " "
1406	6872	168m	Road access
1132	Mairaki Dns No2	283m	Road Access, now destroyed?
1131	Burnt Hill	368m	Road access
1142	Mt Grey	934m	Road access, private road
1144	Mt Cass	526m	Road access, " "
1408	Mt Oxford	1356m	Helicopter
1123	High Peak	968m	Helicopter
1402	Ben More	1657m	"
1401	Castle Hill	1986m	"
1410	Sugar Loaf	1359m	uncertain
1409	Hamilton Peak	1917m	Helicopter
1400	Mt Enys	2195m	"
nnnn	Peak Hill	1244m	uncertain, not EDS but resected in
1412	Black Hill	2046m	Helicopter
1143	Okuku Hill	1143m	uncertain
nnnn	Darfield		
nnnn	Annat		
nnnn	Kowai R Bridge		
nnnn	Porters Pass		
nnnn	Broken River Bridge		
nnnn	Lake Pearson		
nnnn	Corner Knob	778m	Trig, Road access
nnnn	Waimakariri Bridge		
nnnn	Bealey/Edwards confluence		
nnnn	Arthurs Pass Township		
nnnn	Dobson Memorial, Trig		

nnnn Warnocks Knob, 1167m 1km walk from road
nnnn Trig F, 1km walk and 400m climb
nnnn Otira Township
nnnn Footbridge over Otira River
nnnn Trig 5272, 251m 400m flat from road
nnnn Between railway line and river
nnnn Trig 5271 in Jacksons, too close to hill? - better near railway
3508 Z, Inchbonnie FMP
3512 BM4, Inchbonnie FMP
3502 B, Inchbonnie FMP
3501 A, Inchbonnie FMP
3503 W, Inchbonnie FMP
nnnn Trig 5831 at corner of Taramakau. Benchmark may be better
nnnn Trig 5182
nnnn Dillmanstown benchmark available
nnnn Kumara Junction " "
1421 J Blue Spur 300m Road access
1420 Mt Greenland 905m 4WD access (Phase A site)

New station numbers will be assigned as follows:

5001 - 5100 Completely new station
5101 - 5200 Any pre-existing trig or benchmark

PHASE C SITES: (25 sites)

The following will certainly be observed.

2404 EA18, New Plymouth
1501 Bluff Hill No3, Napier (BLUF)

Some of the following may be observed.

3521 A Totara Park
3524 D Totara Park
5301 Johnson EDS
5302 Mains Rock CP017/S1540R (WRC)
5303 Trig 16146
5304 Flagstaff
5305 Haywards GPS
5306 Trig 16097 (Taita)
5307 Whitby
5308 Hill Road Summit
5309 Liverton Road
5310 North Belmont Road
5311 Horokiri Stream
5312 Pukerua Bay
5313 Whitireia Park
5314 Karehana Bay
67402 Barclay No2
67501 Nob
67505 Bon
68202 Colonial Knob EDS
68206 Koro
68301 Climie No2
68303 Tasvac

Any other new station numbers will be assigned as follows:

5301 - 5400 Completely new station